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The study of an Economic Integration of a Microgrid for the University of Management and Technology Sialkot

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ABSTRACT

The finest microgrid design has been proposed in this research to ensure a smooth energy supply for the University of Management and Technology (UMT) Lahore, Sialkot Iqbal campus, Pakistan at the cheapest price. The design methodology considered resource availability, environmental feasibility, economic feasibility, and renewable integration. The university can utilize the energy from the Sun, fossil fuel, and national grid. Integrating the available energy resources, data collection, and forecasting multiple parameters were simulated to design the optimal microgrid. The optimal design is selected based on the net present cost (NPC), renewable fraction (RF), operating cost (OC), repair and maintenance cost (O and MC), etc. Out of the 48 viable simulated designs, the optimal design has a PV system, generators, and the grid to fulfill energy demand at a net present cost of $116,987, with a renewable portion of 95%. In contrast, the worst simulated design depends on generators and battery backup, resulting in a $2.93 million NPC with a renewable segment of 24.3%.

1. Introduction

The diminution and unreliability of fossil fuel reserves, greenhouse gas emissions, and burning energy charges (increasing energy prices) have forced the world to move toward renewable energy [1, 2]. The part of local establishments in shifting towards renewables was highlighted in the Paris Agreement 2015 [3-8]. Remarkable progress in microgrid research has yielded a substantial body of literature delving into these systems' multifaceted benefits, challenges, and opportunities [9, 13].

After a detailed feasibility study under different environmental scenarios, a microgrid based on a PV system and wind turbine was designed for Cyprus [14-20]. Due to the increasing fuel prices, the researchers in [21] have developed a microgrid based on PV, Wind, fuel cell, and BESS using the latest design tool, HOMER. This design has shown a remarkable reduction in carbon dioxide emissions [21].

The contribution of these researchers highlighted the need and worth of optimizing microgrids for a better future. Furthermore, the role of mathematical modeling in renewable energy systems emerged [22]. Based on mathematical modeling software like HOMER design, simulate, compare, and suggest the best energy-yielding strategies for the entire life of renewable systems.

Additionally, integrating renewable and non-renewable hybrid microgrid designing and simulation has also been introduced to get the optimal energy supply considering the reliability, continuous supply, and economically friendly combinations [22].

Multiple designs of microgrids have been proposed so far based on the site and requirements. Researchers in [23] proposed an off-grid microgrid design that is 100% based on renewable energy resources with a battery backup for a remote location.

Further, the strength of algorithms like particle swarm optimization, has been utilized in designing a microgrid optimal resource selection to supply cheap energy to the customers [24].

A study to supply cheap and reliable energy to Kish Island in Iran was conducted and came up with a worthy microgrid design composed of PV, wind, generators, and battery backup [25]. Additionally, a noticeable decrease of 50% in the cost of energy was achieved by incorporating the solar trackers.

Optimization of microgrids can be performed by considering various factors like material, circuits, algorithms, etc. Scientists [26] used a harmony search algorithm to enhance the efficiency and economic viability of microgrids.

In a project for a university in Istanbul, the research team designed a system using HOMER that came up with the grid-tied hybrid microgrid with hydrogen energy storage as the most optimal solution [27].

This research study is conducted to design an optimal microgrid design to ensure a cheap, reliable, and uninterrupted energy supply for UMT Sialkot, Pakistan.

To achieve this, the data related to the site, load, existing conventional and renewable energy resources, economics, environment, etc. is gathered and processed to predict their values for the coming 25 years. Further, simulations have been made using HOMER-Pro software to evaluate the performance of standalone and integrated resources at multiple criteria like, operating cost, initial cost, maintenance cost, renewable fraction, uninterrupted energy supply, cheap energy supply, payback period for renewable energy, etc. for 25 years of operation. The research methodology is depicted in Fig. 1.

The paper is organized into three main sections 1-Introduction, picturizing the concepts and worth of the proposed research, followed by 2- Methodology, presents the methods applied to solve the problem, 3-Results and Discussions, observing the outcomes of the research, and Conclusion, presents the conclusion of complete research work.

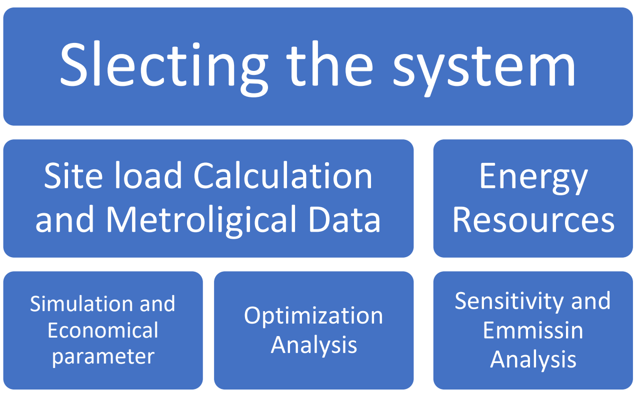

Fig. 1. Research Methodology

2. Methodology

2.1 Load Calculation

The load scheming is very significant in this research. The scheme is planned considering the crowning load of the site. Details are provided in the Table 1.

Table 1

Basic calculation of UMT Sialkot Iqbal campus Pakistan

Month	Monthly Units (KWH)	Unit/ Day	SPV Size (KW)	Avg: Load KW
Jan:	26560	823.33	(823.33/365/3.5) = 232.02	36.890
Feb:	9840			13.670
March:	25680			35.670
April:	32080			44.560
May:	43680			60.670
June:	21840			30.330
July:	41165			57.180
Aug:	21735			30.210
Sept:	18249			25.350
Oct:	15870			22.040
Nov:	9258			12.860
Dec:	30442			42.250

The sum load of the UMT campus/site is 231KW. Keeping in view the load and available energy resources, the microgrid is designed.

2.2 Energy Resources

The offered energy resources at the site are the grid, diesel generator, solar photovoltaics, and batteries. Another renewable energy resource available at the site could be biomass but that causes pollution (we are not comparing, we are considering both as pollution-causing sources) and therefore is not included in the design. However, the generator is the part only in case of emergency.

2.3 Solar Energy

The average annual data of solar illumination at the site is sourced from the National Renewable Energy Laboratory database and is presented in the Fig. 2.

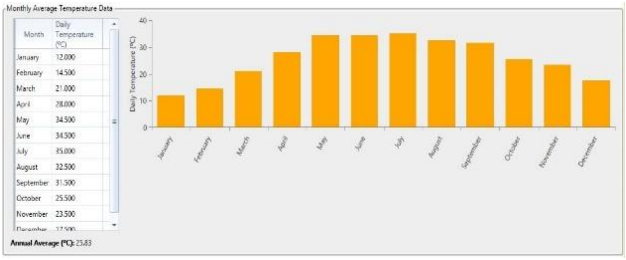

Fig. 2. Bar Chart Of Illumination Per Year

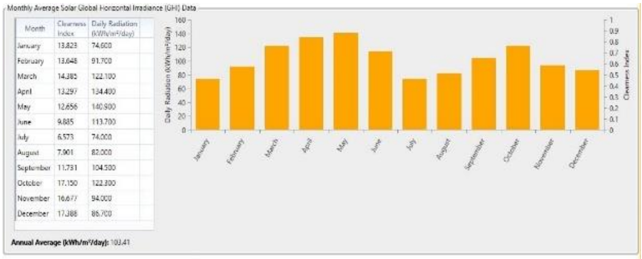

Fig. 3. Bar Chart Of Temperature Per Year

The average daily solar radiation in Sialkot, Pakistan, typically ranges from about 4.5 to 6.5 kWh/m² or 4.5 to 6.5 sun hours per square meter (h/m²) on a typical day. According to the chart, January records the lowest temperature at 12°C, highlighting the colder conditions during the winter season. In contrast, the temperature peaks in June, reaching 35°C, indicative of the warmer temperatures experienced during the summer months.

Table 2

Average daily illumination and temperature at UMT University

Month	Clearness Index	Average Daily Illumination W/m2/day	Average Daily Temperature 0C
January	13.823	74.600	12.000
February	13.648	91.700	14.500
March	14.385	122.100	21.000
April	13.297	134.400	28.000
May	12.656	140.900	34.500
June	9.885	113.700	34.500
July	6.573	74.000	35.000
August	7.901	82.000	32.500
September	11.731	104.500	31.500
October	17.150	122.300	25.500
November	16.677	94.000	23.500
December	17.388	86.700	17.500

2.4 Proposed Design

The proposed microgrid design for the UMT Sialkot site in Pakistan encompasses a wide range of energy sources aimed at optimizing energy production. The key components integrated into the microgrid design include the national grid, diesel generator, solar photovoltaics, and battery bank as depicted in Fig. 4.

Fig. 4. Proposed Microgrid Design

2.5 Electrical Load

The load for one year is measured for each hour. A load after the shutdown of the university (6:00 pm) and before the commencing of classes (9:00 am) is zero. Therefore, the data lies in the time limit of 09:00 am to 06:00 pm. The measured data of a load for each month is presented in Table 1. The monthly load profile for the site is presented in Table 3.

Table 3

Monthly load profile for UMT Sialkot Iqbal Campus University in (kW)

	Jan:	Feb:	March:	April:	May:	June:	July:	Aug:	Sep:	Oct:	Nov:	Dec:
9:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250
10:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250
11:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250
12:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250
13:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250
14:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250
15:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250
16:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250
17:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250
18:00	36.890	13.670	35.670	44.560	60.670	30.330	57.180	30.210	25.350	22.040	12.860	42.250

2.6. Solar Photovoltaic

In the proposed microgrid design, the solar PV system parameters are as follows:

- Flat plate type solar PV panels from Peimar Inc. with a rated capacity of 233 kW, selected to align with the energy consumption of UMT Sialkot Iqbal Campus.
- Monocrystalline photovoltaic cells, chosen for their commendable efficiency of 17.30%, are employed in the HOMER simulation.
- Each module weighs 14.5 kg, occupies an area of 1.277 m², and operates with a derating factor of 96% to address real-world conditions such as soiling, wiring losses, shading, snow cover, and aging.
- Ground reflection of solar illumination is assumed to be 20%, as per HOMER's definition of ground reflectance.
- The simulation excludes mechanical tracking, and maintains a panel slope of 33.15 degrees, but incorporates maximum power point tracking.
- The nominal operating temperature is set at 25°C, with a default temperature coefficient of -0.400, representing the temperature effects on the production of the photovoltaic system.
- The initial capital cost for the solar PV module is based in Lahore, Pakistan, with a cost of $0.15/W, serving as both the initial and replacement cost in the simulation.
- The HOMER software allocates a 25-year lifetime for the photovoltaic modules.

Collectively, these parameters form the foundation for the comprehensive simulation of the solar photovoltaic system, as summarized in Table 3 2. This meticulous approach ensures a thorough understanding of the system's performance, economic viability, and potential contribution within the proposed microgrid.

Table 4

Data of solar photovoltaic system

Solar Photovoltaic	Description of Parameters	
Producer	Peimar lnc.	
Name		PeimarSG200M5
Category	Flat Plate	
Evaluated Capacity	233	KW
Effectiveness	17.30	%
Principal Cost	37727.13	$/KW
O and M	1238	$/Year
Lifetime	25	Years
Operating Temperature	45	Degree
Weight	14.5	Kilogram

The operational parameters of the simulated solar photovoltaic system are comprehensively outlined in Table 3.3, encompassing key metrics such as rated capacity, mean output per day, capacity factor, output range, photovoltaic penetration, and total energy production.

This comprehensive overview provides a detailed understanding of the operational characteristics and performance metrics of the simulated solar photovoltaic system, facilitating a nuanced analysis of its efficiency and effectiveness.

Table 5

Description of solar photovoltaic system

Quantity	Value	Units
Evaluated Capacity	233	kW
Mean O/P	63.3	kW
Mean daily O/P	1519	kWh/d
Capacity Aspect	27.1	%
Production	554439	kWh/Year
Least O/P	0	kW
Extreme O/P	214	kW
Photovoltaic	440	%
Operating time	4,383	hrs/yr
Levelized Fee	0.00496	$/kWh

2.7 Diesel Generator

All the parameters of the diesel generator are carefully selected by keeping the complete load scenario in view. All the parameters and expenditures mentioned in the simulation are updated.

The details of the parameters of a 150kW diesel generator are presented in Table 6.

Table 6

Description of diesel generator

Diesel Generator	Description of Parameters	
Manufacturer	Generac	
Capital Cost	25000	$
Replacement Cost	25000	$
O and M	31.839	$/1op.hour
Fuel Price	0.98	$/L
Lifetime	15000	Hours

The operational life of a diesel generator is 131 hours/year. It is defined as, “Operational life means the designed or planned period during which a facility remains operational while being subject to permit conditions, including closure requirements. Operational life does not include post-closure activities."

Table 7

Properties of diesel generator

Diesel	
Curve Intercept (L/Hour)	3.15
Curve Slope (L/Hour/kW)	0.264
Emissions	
Carbon monoxide (g/l fuel)	12.44
Intact (g/l fuel)	0.72
Particulate matter (g/l fuel)	0.056
Diesel Sulphur to PM (%)	2.20
Nitrogen (g/l fuel)	14.22
Diesel	
Lesser Thermal Value (MJ/kg)	43.2
Concentration (kg/m3)	820
Carbon (%)	88
Sulfur (%)	0.4

Table 8

Operational data of diesel generator

Quantity	Value	Units
Operating hours	271	hrs/yr
Started	131	starts/yr
Active Life	55.4	Hrs/yr
Capacity Factor	0.786	%
Fixed Rate	36.6	$/hr
Marginal Rate	0.259	$/kWh
Energy	10333	kWh/yr
Mean O/P	38.1	kW
Lowest O/P	37.5	kW
Supreme O/P	70.4	kW
Fuel Utilization	3583	L
Specific Fuel utilization	0.347	L/kWh
Fuel Energy I/P	35253	kWh/yr
Efficiency	29.3	%

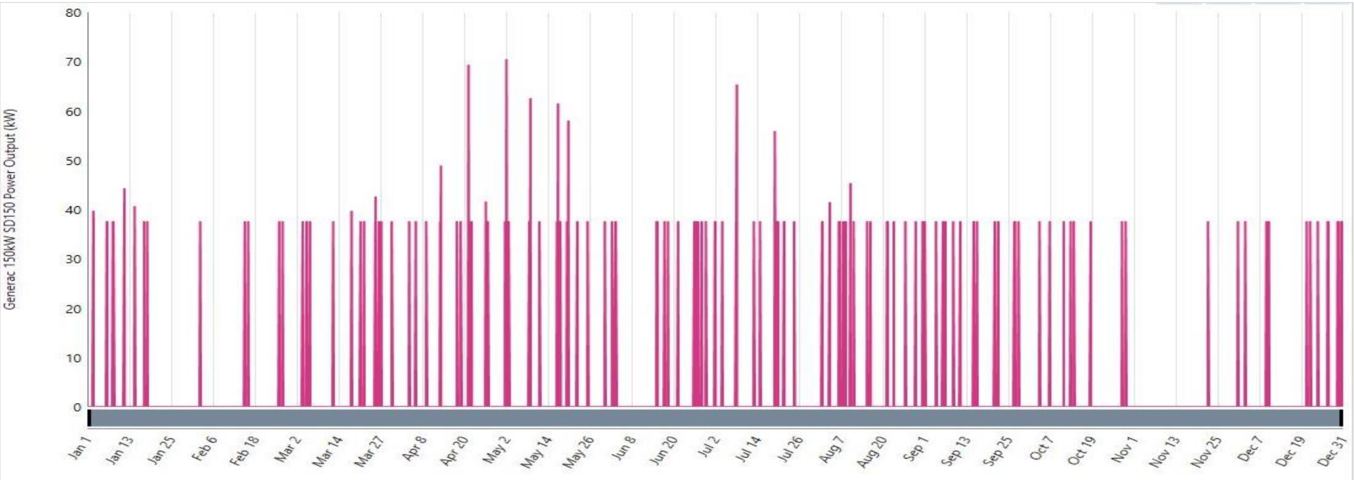

Fig. 5. Fixed Capacity Power Output of Diesel Generator

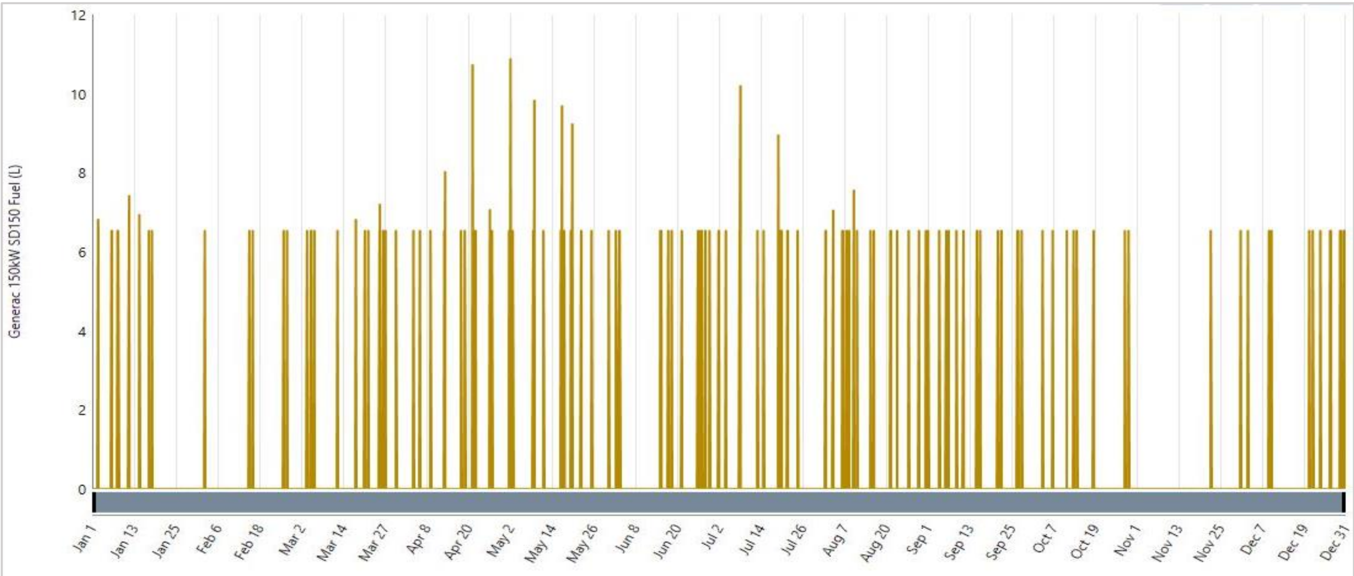

Fig. 6. Fixed Capacity Fuel of Diesel Generator

Further, the fixed capacity power output, and the fixed capacity fuel of the diesel generator integrated into the proposed design of the microgrid to serve the load of UMT Sialkot Iqbal Campus Pakistan, are presented in Fig. 5, and Fig. 6 Respectively.

2.8 Electricity Grid

The initial design has included the grid contribution to ensure an uninterrupted energy supply. Considering the load shedding issue of Pakistan, the voltage outage of an average of one hour is implemented in the simulation of HOMER. A load of the university needs to be attended from 09:00 am to 06:00 pm on the weekdays (excluding Saturday and Sunday). Therefore, calculating the average one-hour daily load shedding, the total outage becomes 281 hours in one year. The scenario of a power outage is also depicted in Fig. 7.

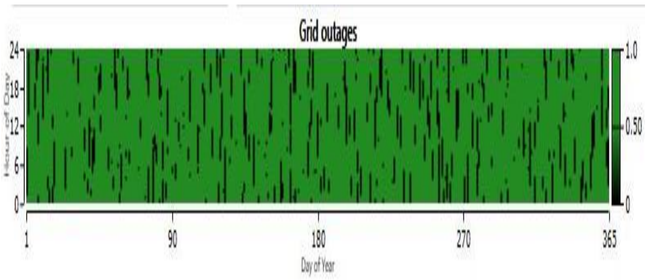

Fig. 7. Grid Power Outage in One Year

2.9 Bidirectional Power Converter

A converter of 300KW is used to keep the bidirectional power flow. It has a $600 replacement cost with a lifetime of 10 years. The real-time capital and replacement costs have been used in the simulation. It operates at 98% efficiency which is impressive. The specification of the bidirectional power converter is summarized in Table 9.

Table 9

Specifications of bidirectional power converter

Bidirectional Converter	Description of Parameters	
Manufacturer	Generic	
CC	600	$/kW
Rep: Cost	600	$/kW
OMC	0	($/year)/Year
Time	10	Years
Inverter input efficiency	98	%
Comparative Capacity	85	%
Rectifier input efficiency	98	%

Table 10

Operational parameters of bidirectional power converter

Amount	Inverter	Rectifier	Units
Capacity	300	255	kW
Mean O/P	56.1	0	kW
Minimum O/P	0	0	kW
Maximum O/P	210	0	kW
Capacity Factor	18.7	0	%
Operating Hrs	4,172	0	hrs/yr
Power Out	491,320	0	kWh/yr
Power In	501,347	0	kWh/yr
Loss	10,027	0	kWh/yr

The value of energy out and energy in recorded for power converter are 491320 kWh/year, and 501347 kWh/year respectively. Each component has its power losses, the power losses associated with the power converter are 10027 kWh/year.

The input and output of the bidirectional power converter is presented in the graphical form in Fig. 8, and Fig. 9 Respectively. Further, the operational summary of the power inverter for every single day for a complete year is summarized in Fig. 10. Renewable energy output per month is presented in Fig. 11.

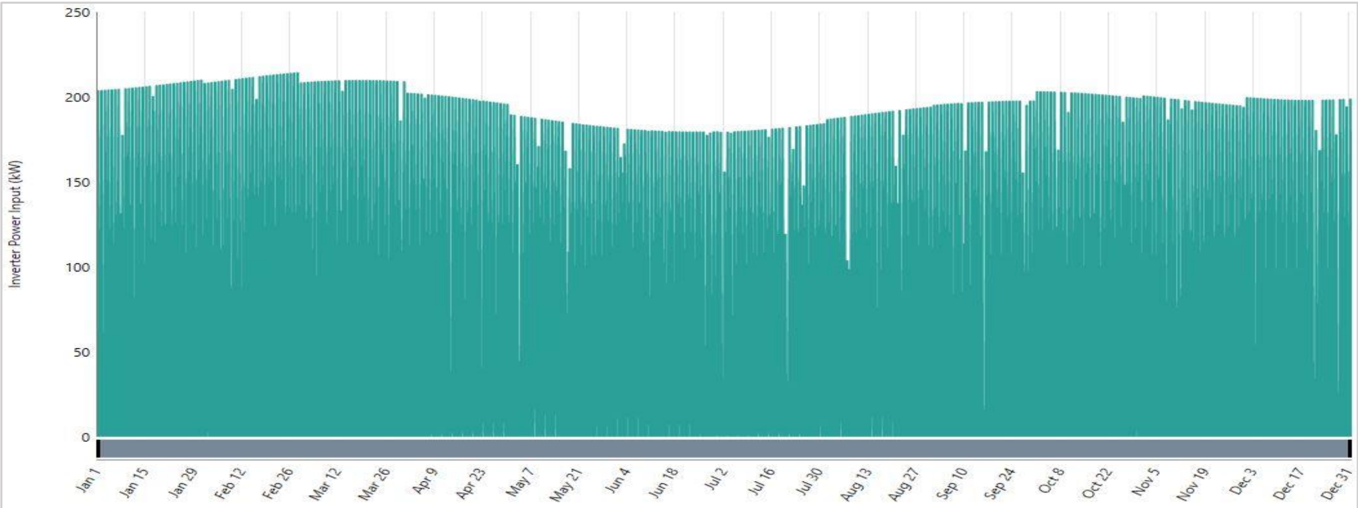

Fig. 8. Power Input of Inverter

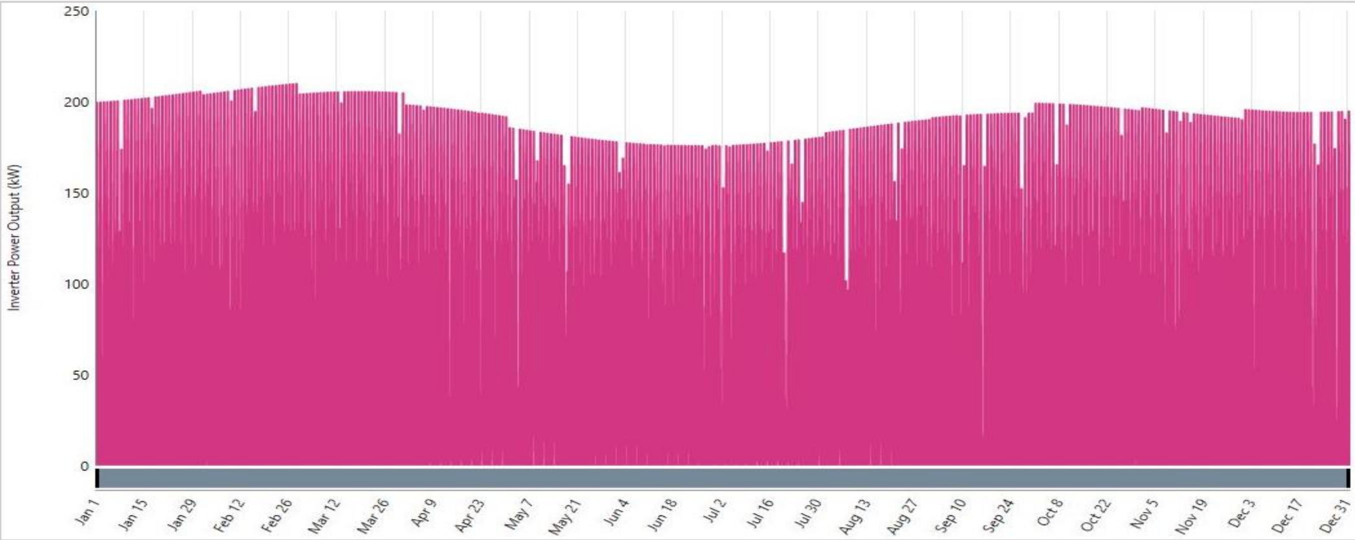

Fig. 9. Power Output of Inverter

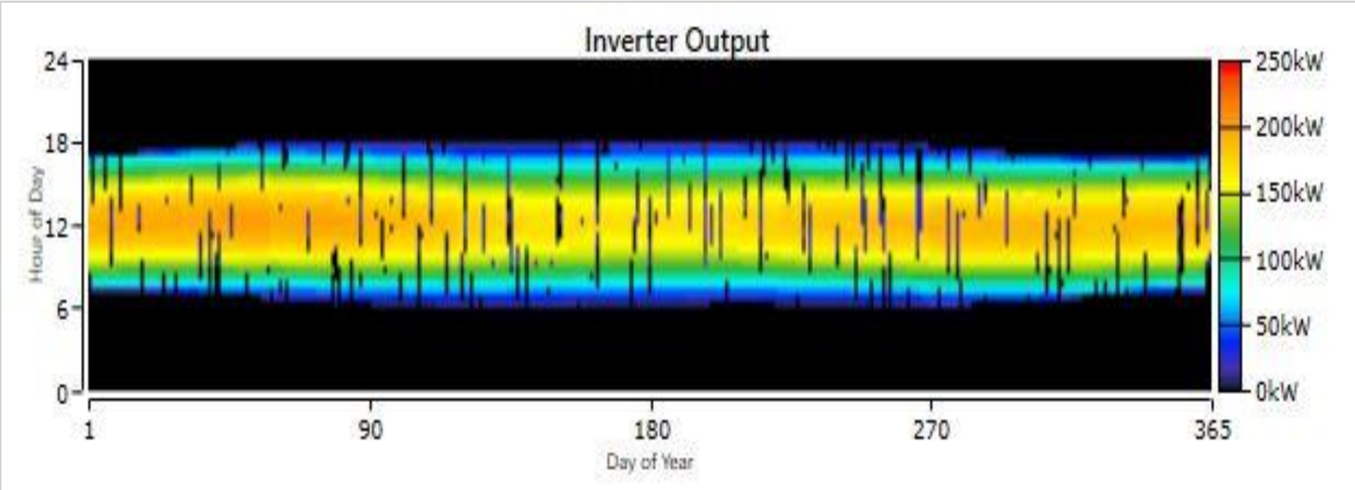

Fig. 10. Operational Summary of Power Inverter

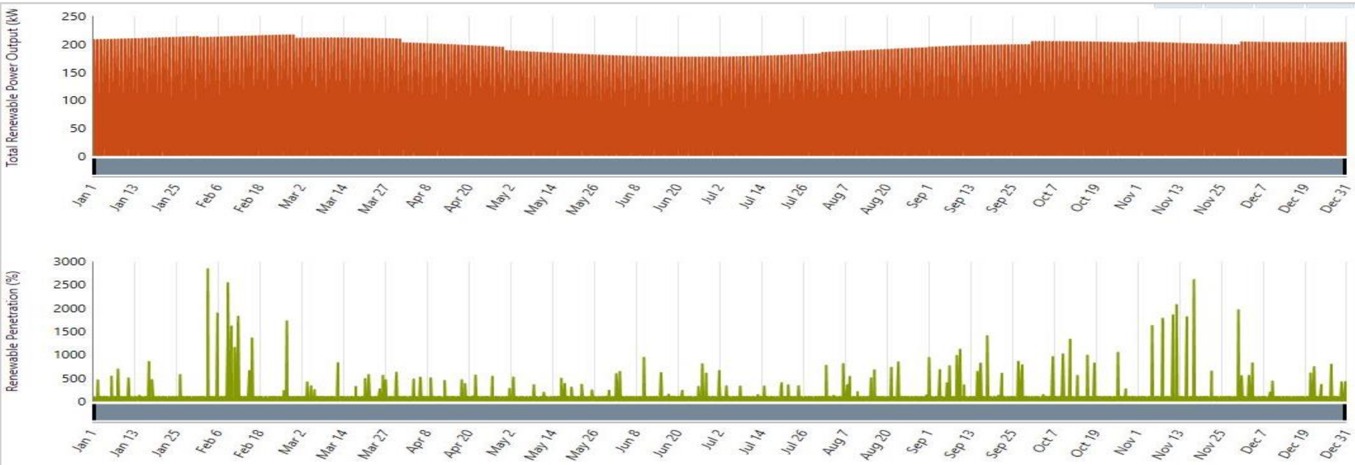

Fig. 11. Renewable Participation

3. Result and Discussions

3.1 Optimization of Microgrid

The ultimate purpose of this research is to ensure the uninterrupted quality energy supply to the University of Management and Technology Sialkot, Iqbal campus, at the cheapest price using the most suitable energy resources at the site. The standard parameters to evaluate the design of microgrids are operating cost, net present cost, initial capital cost, renewable fraction, and levelized cost of energy.

Every parameter is included to ensure the best fit. Afterward, the data is simulated in HOMER Pro software (specially designed for the microgrid optimization by NREL) where every possible scenario is simulated and the optimal design comes up to fulfill the requirement. The top two designs are presented in Table 3. Remember the target is to get the optimal combination of energy resources in terms of time and the percentage of utilization of energy resources to ensure the uninterrupted energy supply at the cheapest rate.

Table 11

Optimized design of microgrid proposed

Group	SPVS (KW)	Gen. (KW)	N.G (KW)	Conv. (KW)	NPC ($)	COE ($)	OC ($/Year)	CC ($)	Ren: Frac: (%)
01	233	150	3000	300	116987	0.00895	2146	63327	95.0
02	233	150	N/A	300	2.93M	0.929	114655	63327	24.3

Deep performance analysis of the two optimal designs of the microgrid proposed by the HOMER is summarized in sequence in Table 12, and Table 13 Respectively for the 25 years of life. The total cost of the optimal microgrid system for 25 years is presented in Table 12 is $150,904.28, whereas the total cost of the second optimal is $2,890,133.14 respectively. The data for each scenario or design presented in Table 12, and Table 13 Has proved that the first scenario/design of the microgrid proposed by the HOMER is the most suitable power system to fulfill the energy demands of UMT Sialkot Iqbal Campus Pakistan, for the 25 coming years.

The economic evaluation is presented in Table 14 The top proposed design has the minimum payback period, highest return on investment, and highest internal rate of return. Additionally, the first optimal design has the highest renewable fraction of 95%.

Table 12

Net present cost summary of optimal design of microgrid

Element	CC ($)	Rep: Cost ($)	OMC ($)	Petroleum ($)	Salvage ($)	Final ($)
Generac 150kW SD150	$25,000.00	$0.00	$215,709.23	$87,775.08	($13,708.33)	$314,775.97
Grid	$0.00	$0.00	($234,048.82)	$0.00	$0.00	($234,048.82)
Leonics MTP-4117H 300kW	$600.00	$1,200.00	$0.00	$0.00	($300.00)	$1,500.00
Peimar SG200M5	$37,727.13	$0.00	$30,950.00	$0.00	$0.00	$68,677.13
System	$63,327.13	$1,200.00	$12,610.41	$87,775.08	($14,008.33)	$150,904.28

Table 13

Net present cost estimation for scenario-2

Element	CC ($)	Rep: Cost ($)	OMC ($)	Petroleum ($)	Salvage ($)	Final ($)
Generac 150kW SD150	$25,000.00	$100,000.00	$1,977,201.90	$809,431.24	($21,500.00)	$2,890,133.14
Leonics MTP-4117H 300kW	$600.00	$1,200.00	$0.00	$0.00	($300.00)	$1,500.00
Peimar SG200M5	$37,727.13	$0.00	$30,950.00	$0.00	$0.00	$68,677.13
System	$63,327.13	$101,200.00	$2,008,151.90	$809,431.24	($21,800.00)	$2,960,310.27
Generac 150kW SD150	$25,000.00	$100,000.00	$1,977,201.90	$809,431.24	($21,500.00)	$2,890,133.14

Table 14

Annualized cost summary of optimal design of microgrid

Element	CC ($)	Rep: Cost ($)	OMC ($)	Petroleum ($)	Salvage ($)	Final ($)
Generac 150kW SD150	$1,000.00	$0.00	$8,628.37	$3,511.00	($548.33)	$12,591.04
Grid	$0.00	$0.00	($9,361.95)	$0.00	$0.00	($9,361.95)
Leonics MTP-4117H 300kW	$24.00	$48.00	$0.00	$0.00	($12.00)	$60.00
Peimar SG200M5	$1,509.09	$0.00	$1,238.00	$0.00	$0.00	$2,747.09
System	$2,533.09	$48.00	$504.42	$3,511.00	($560.33)	$6,036.17

Table 15

Annualized cost estimation for scenario-2

Element	CC ($)	Rep: Cost ($)	OMC ($)	Petroleum ($)	Salvage ($)	Final ($)
Generac 150kW SD150	$1,000.00	$4,000.00	$79,088.08	$32,377.25	($860.00)	$115,605.33
Leonics MTP-4117H 300kW	$24.00	$48.00	$0.00	$0.00	($12.00)	$60.00
Peimar SG200M5	$1,509.09	$0.00	$1,238.00	$0.00	$0.00	$2,747.09
System	$2,533.09	$4,048.00	$80,326.08	$32,377.25	($872.00)	$118,412.41

4. Conclusion

A microgrid for UMT Sialkot is designed to ensure an uninterrupted energy supply at the cheapest price. The system is designed for 25 years after forecasting the data for load, illumination, temperature, purchasing and operation costs of the system, etc. The designed system is then simulated using the HOMER Pro software to evaluate its performance and consider all possible scenarios to select the most suitable design. The optimal integration with marked contribution in percentage for energy supply for each resource includes a grid, diesel generator, and a solar photovoltaic system. Of course, solar is set as a priority and the use of diesel is just for emergency cases.

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